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EVAPORATION IN A BOG HABITAT.*

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Within the past two years, investigations have been carried on at a bog island in the Licking Reservoir near Columbus, Ohio, disclosing the toxicity of bog water, and bog soils. The physiological aridity of this bog habitat has been discussed in two papers, (1 and 2). In connection with experiments, which are to be made upon the transpiration of bog plants, it was thought desirable to obtain direct evidence concerning the evaporating power of the air of this region. With this object in view, the data given below were collected during the past summer.

The problem of evaporation, though manifestly an important one, has received relatively little attention. Recent investigations at Salton Sea in Southern California, have brought to the attention of meteorologists, the vital importance of evaporation in the storage of water in reservoirs, for irrigation purposes in the arid regions of the west. Salton Sea, which is cut off from the Colorado River, must, in the course of ten or twelve years, it is estimated, be reduced by evaporation, and it is planned, therefore, to make a complete study of the phenomenon in that region. Readings are taken from floating tanks and pans upon water surfaces at different points on the sea, and likewise at auxiliary stations in different climates and under different conditions.

Considered purely from a physical standpoint, evaporation depends upon humidity, temperature, and wind velocity. The sun's rays influence it only as they increase the temperature of the air and of the evaporating surface. Secondary factors influencing evaporation are, however, so numerous, and difficult to separate, since they all may operate at the same time, that it is

*Contributions from the Botanical Laboratory of Ohio State University, L.

not an easy task to find a uniform and constant relationship for each one of the primary factors. It must be remembered, therefore, that the following statements from a summary of the subject in the "Monthly Weather Review" of 1907 and 1908, (8) hold true only when all other things are considered equal.

If the rainfall is uniformly distributed throughout the year, the evaporation will increase proportionately.

A heavy winter, and a light summer rainfall will, together show a small annual evaporation, and conversely.

Evaporation varies nearly inversely as the atmospheric pressure, or nearly directly as the altitude.

The rate of evaporation is nearly proportionate to the difference of temperature as indicated by the wet, and dry bulb thermometers.

As to temperature, it is found that the capacity of atmospheric air for moisture is approximately doubled with every increase in atmospheric temperature of 20° F.

Wind velocity has a marked influence upon evaporation being nearly in a direct ratio with it.

In the light of these observations, meteorologists have attempted to find the relationship existing between the various modifying factors and evaporation, and have succeeded in working out formulas by means of which the evaporation from watersheds and water surfaces can be approximated.

It should be stated that there are many obstacles to contend with in devising proper methods for measuring evaporation. It is almost impossible, in field work, to place the instrument under normal standard conditions, and also to eliminate the error caused by rainfall. It has been pointed out, moreover, that the evaporation from a large water surface cannot be calculated correctly from the evaporation of a small tank for the reason that air, moving over a water surface, absorbs moisture, and its capacity to hold water becomes gradually less.

This difficulty may be partially overcome by measuring the evaporation at numerous points on the water surface, plotting the results and drawing isothymes. By a summation of the evaporation over the areas between the isothymes, the evaporation of the whole area can be calculated with comparative accuracy.

New and more improved instruments have been devised, and are now being employed by the Weather Bureau (10) in connection with the work upon evaporation from lakes and reservoirs.

In physiological work, it has been considered preferable to obtain the evaporation readings directly by such instruments as are available, rather than to depend upon formulas, which are necessarily somewhat inaccurate, The German Forest Service (9) has used a small zinc receptacle with a wooden roof, which allows the free access of air, but excludes rainfall. Within recent years the porous cup atmometer, which will be described later, has come into use.

Livingston's experiments (3) with the atmometer at Tucson have shown that the evaporating power of the air, aside from its indirect effect upon soil moisture, is an important factor in plant development. Several species of plants were grown in soil which was kept as nearly as possible at its optimum moisture content, and their behavior in relation to the rate of evaporation was studied. Two species which were able to transmit water to the leaves faster than it was lost by transpiration, grew vigorously, even during a period of drought. Several other varieties were unable to provide the excess water for growth during the period of drought, but remained quiescent, and resumed their growth upon the return of the season of lower evaporation. Other plants not only failed to provide the excess water for growth during the drought, but did not respond even on the coming of the season of lower evaporation and soon died. It is concluded, from these experiments, that the evaporating power of the air controls desert vegetation to a great extent, for it inhibits the growth of plants which are not able to adjust themselves to the low evaporation rate, and thus plays an important part in the determination of centers of plant distribution.

Further work (4, 5,) has brought out the value of the atmometer in the differentiation of habitats. While the amount of rainfall, through its effect upon soil moisture, is effective upon vegetation over large areas, the evaporating power of the air may vary greatly within these areas, and within neighboring habitats. Data taken in the Missouri Botanical Garden showed that the average ratio of the evaporating power of the air in the open field, and in the shade of a coppice was approximately as 2.5 to 1. About the same ratio was apparent in an open strawberry patch, and beneath a shade tent.

Atmometer readings taken at Tucson, and at different altitudes in the Santa Catalina Mountains indicate a gradual decrease in the rate of evaporation with altitude. Considering as unity the standard Tucson atmometer at 2412 feet, the relative loss of the instruments at 6000, 7500, and 8000 feet, was .8, .5 and .4 respectively. These conclusions with reference to the decreasing rate of evaporation at higher altitudes have been corroborated by similar experiments conducted by Shaw in the Selkirks (6).

Transeau (7) continued the study of the relation of plant societies to evaporation. He placed instruments in different plant habitats about Cold Springs Harbor, Long Island, comparing all readings with that of a standard instrument in the Carnegie Garden. He reported an evaporation of 100% on an open gravel slide, and showed that the partial invasion of the slide by vegetation produced a decrease of 40% in evaporation. The rate in a forest habitat varied from 50% in the open wood to 10% in the swamp forest. In the light of these data, it is easy to see why plants, accustomed to the swamp environment, cannot succeed in an open woods with a rate of evaporation five times as great. The importance of pioneer shade plants as reducers of transpiration is also pointed out.

The instruments used at Buckeye Lake were a slight modification of those used by the writers just mentioned. The evaporation takes place from the surface of an exposed porous clay cup, about thirteen centimeters in length, two and one-half cm. in diameter, and with a wall of four millimeters thickness. The upper end is closed, and rounded, the lower end is closed tightly by a perforated rubber stopper, through which passes a glass tube. This tube extends down to the bottle below, which serves as the reservoir of water. Since the instruments were to be left for rather long periods of time, a larger and more stable form of reservoir was required. In place of the "Mason" jar and cork stopper, a bottle of 5000 cc. capacity was used, with a neck of sufficient slope so that the water level could readily be seen from above. At the mouth of the bottle, the glass tube passed through two rubber stoppers, the one a two-holed stopper inserted in the bottle, and the other with its large end down, covering the hole, and preventing the entrance of water, but allowing free access of air. A file mark near the top of the bottle indicated the point to which the water level was raised on refilling. Throughout the experiment only distilled water, containing a small per cent of formaldehyde, was used.

The interior of the cup remains free from air because of the surface tension of the water films closing the pores. The cup thus remains filled with water, and as evaporation takes place at the surface, more water is forced up from below into the vacuum by the air pressure upon the water surface in the reservoir.

The porous cups used in this work were obtained through Dr. Dachnowski from the Carnegie Institute and were standardized at the Desert Laboratory at Tucson.

When used during the growing period of plants, the principal defect of this instrument is that rain may enter the reservoir through the porous cup, and thus cause an error in the results. If daily readings are taken, the length of time of precipitation can be recorded, and corrections made for the error. But in taking readings at intervals longer than a day, this error must be neglected.

One instrument was placed in a station of the Maple-Alder zone near the border of the island and was shaded by Acer rubrum, Alnus rugosa, and Rhus vernix. Osmunda cinnamomia, O. regalis, and Dryopteris cristata were growing nearby. The other station was in the central zone, where the principal plants were Sphagnum, Oxycoccus oxycoccus, Drosera rotundifolia, Eriophorum virginicum, and Dulichium arundinaceum.

Readings were begun May 14, and taken weekly until June 11. No data were taken then until July 17, when the evaporation for five weeks was recorded. Weekly readings were then resumed and taken until August 21, when after another break of three weeks, they were continued until Oct. 2. Unfortunately, the instrument in the central zone was disturbed on August 21, and on September 11, had disappeared entirely. Temperature readings were also taken in the two zones.

FIG. 1. Central Zone Station.

FIG. 2. Station in Maple-Alder Zone.

It was thought that an average of the precipitation and temperature records taken at the stations of the Weather Bureau at Pataskala, Gratiot, and Granville, would represent, approximately, the meteorology of our station at the bog. The records of wind velocity which are necessary to make the observations complete were not obtainable.

The climatology and evaporation data for the bog station are given in the table below:

TABLE I. CLIMATOLOGICAL AND EVAPORATION DATA FOR THE BOG ISLAND AT BUCKEYE LAKE, OHIO.

	Precip.		Temperature in F.					Sunshine			Evaporation		
Date	Precipitation	No. of days of .01 or more rainfall	Mean	Maximum	Minimum	Temperature in Maple-Alder Zone	Temperature in the Central Zone	Days clear	Days cloudy	Days partly cloudy	Maple-Alder Zone	Central Zone	Difference
1909 May 14	....	....	....	....	....	77.	75.2	....	....	....	....	....	....
May 21	1.07	2	61.5	82.	41.5	59.	60.	4	1	2	80.8	98.9	18.1
May 28	1.84	3	59.5	75.5	45.5	69.8	69.8	1	2	4	78.1	97.	18.9
June 4	2.04	5	67.5	84.5	50.5	73.4	78.8	2	2	3	60.5	92.1	31.6
June 11	.87	6	70.5	84.	52.5	77.	78.8	1	2	4	27.5	53.3	25.8
June 19	.25	2	66.	80.	47.	....	....	4	1	3			
June 26	2.30	4	70.5	87.5	43.	....	....	2	1	4			
July 3	1.00	2	77.	90.	59.	....	....	3	....	4	290.4	349.2	58.8
July 10	.02	2	66.6	85.5	46.5	....	....	3	2	2			
July 17	1.91	4	74.	87.	60.	76.1	75.2	1	2	4			
July 24	.46	2	67.	87.	46.	74.3	77.	4	1	2	77.	120.2	43.2
July 31	1.31	3	71.5	88.	51.	82.4	82.4	3	2	2	50.6	69.8	19.2
Aug. 7	.67	2	71.1	85.	55.	82.4	84.2	4	1	2	36.3	69.8	33.5
Aug. 14	.01	1	71.5	90.	53.	80.6	82.4	5	1	1	70.4	82.4	12.
Aug. 21	3.27	2	70.	85.	50.	72.5	72.5	2	1	4	38.5	..	....
Aug. 28	.10	1	69.5	89.	46.5	....	....	5	....	2			
Sept. 4	1.23	3	63.	86.	37.5	....	....	4	1	2	192.5	....	....
Sept. 11	.57	1	64.	79.5	42.	77.	80.6	3	....	4			
Sept. 18	.46	1	68.5	86.	46.	73.4	75.2	5	....	2	38.5	....	....
Sept. 25	.33	2	66.5	83.	46.	67.1	68.	3	....	4	82.5	....	....
Oct. 2	.23	2	53.	71.	33.	63.5	63.5	4	1	2	88.	....	....

An inspection of this table shows that rainfall has had the most marked effect upon the evaporation rate in the Maple-Alder zone, but it is very evident also that this was not the only factor. The influence of temperature in either station is not so apparent for so limited a number of readings. It is quite probable that the missing data for wind velocity would account for some of the results which do not seem to agree with the data at hand.

The effect of the growth of the leaves in the early part of the season, and their fall at the end of the period of observation is quite apparent in the readings of the Maple-Alder zone. The readings of the first and last two weeks in this zone are relatively high. If we consider the time from May to August as the critical period for growth and reproduction in plants, then the greatest evaporation observed is that of May 21 in the Maple-Alder zone, while the greatest loss in the Central zone occurred during the week ending July 24. However, the bearing of these data to plant growth in bogs will be discussed elsewhere.

To Prof. A. Dachnowski, under whose direction this work was planned and carried out, I wish to express here, my sincere appreciation for many helpful suggestions. I also wish to acknowledge the aid of a grant from the McMillin Research Fund, to cover the expenses of the field work.

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